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TURBIDITY IN TORRES STRAIT

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MARITIME SYSTEMS DIVISION
WEAPONS SYSTEMS RESEARCH LABORATORY

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TECHNICAL MEMORANDUM
WSRL-TM-35/89

TURBIDITY IN TORRES STRAIT

P.J. Mulhearn

SUMMARY (U)

The turbidity in the eastern half of Torres Strait, along with other relevant variables, was investigated on two oceanographic cruises in early 1988. Turbidity was high and variable and a regression equation has been developed relating Secchi disc depth (and thence underwater visibility range) to water depth and wind speed. This equation covered 71% of the rms variation in Secchi disc depth. Turbidity was approximately constant with depth in weakly stratified waters, except when they were particularly turbid (attenuation coefficient >1.0 m^{-1}) and then turbidity generally increased with depth with, in some cases, maxima or minima occurring within the water column. Where the temperature and salinity varied markedly with depth a more turbid lower layer was also present. On the second cruise there was a significant correlation between salinity and turbidity in the central waters of eastern Torres strait which had low salinity, and the possible origin of this low salinity water body is discussed.

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1. INTRODUCTION

Torres Strait is a major, narrow seaway used by both local and overseas shipping. The international frontier between Australia and Papua New Guinea also runs through it. Its shallow and narrow waters make it very vulnerable to mining, and mine-clearance would be greatly hampered by the area's strong currents and high turbidity because of the problems they pose for divers and remotely operated vehicles. The high turbidity is discussed in this memorandum.

The term turbidity is used in this report to describe any particulate or dissolved matter in the water which increases its opacity. It can be caused by entrainment of local sea-floor sediments of organic or inorganic origin into the water column; by suspended sediments advected from elsewhere by mean currents (river inputs are one particular example of this); by living plankton and their associated detritus; or by dissolved organic matter. The last, which comes principally from river inputs, is unlikely to have much impact on underwater visibility range. Factors influencing turbidity are wind speed and duration; water depth; tidal currents; mean currents; river input; parameters affecting plankton growth, especially in blooms; and seafloor sediment characteristics, (eg the typical shape, density and quantity of the finer, easily suspended sediments present in those upper layers of the seabed which are affected by near-bottom water currents).

The currents in Torres Strait, both tidal and wind-driven have been discussed in Wolanski (1983,1986), Wolanski and Ruddick (1981),Wolanski and Thomson (1984) and Wolanski et al (1988). Tidal currents are strong, of order 0.5 ms^{-1}; with the semi-diurnal component dominant. Wind-driven currents are an order of magnitude smaller. Hydrology is discussed in Wolanski (1986) and Wolanski et al (1984). The last reference includes a few observations on turbidity, which are discussed in Section 4 of this memorandum. Seafloor sediments in Torres Strait are described in Maxwell (1968, 1973), Harris (1988) and Harris et al (1988).

In early 1988 two oceanographic cruises were conducted in eastern Torres Strait to investigate, at that time of the year, the level of turbidity in the area (measured quantitatively in terms of its effects on light transmission); its spatial and temporal variabilities and the environmental factors which controlled them; and the nature and possible origin of the particulate matter in suspension. The last of these will be discussed in a separate report. In this report the measurements of water turbidity, temperature, salinity and of other environmental variables are presented and conclusions drawn from them. The experiment program and methods are discussed in Section 2. Results are presented in Section 3 and discussed in Section 4. Conclusions are presented in Section 5.

2. EQUIPMENT AND METHODS

Measurements on water clarity, profiles of temperature and salinity, and suspended sediment samples were obtained on two oceanographic cruises in Torres Strait in February and March 1988. Measurement stations for the first cruise, which was on the patrol boat HMAS Bendigo on 16 and 17 February, are shown on figure 1. HMAS Cook took some ancillary measurements. Those for the second cruise, using HMAS Cook from 12 to 15 March and the patrol boat HMAS Launceston on 14 and 15 March, are shown on figure 2.

2.1 Turbidity measurements

Data on turbidity were obtained with a standard Secchi disc and with a Montedoro - Whitney Corporation Model TMU-1B Turbidity Monitor, which is a combined transmissometer and nephelometer. (A transmissometer measures transmittance, or the ratio of transmitted to emitted radiant flux. A nephelometer measures the quantity of scattered radiant flux, in this case that scattered through 90^{o}.)[1]

2.1.1 Transmissometer

Field comparisons between the Secchi disc and the transmissometer provided an approximate calibration of the latter. The transmittance, T, can be written as

$$T = e^{-cl}, \tag{1}$$

where l = the distance the light is transmitted, and c = the attenuation coefficient for the wave-length band of the transmitted light. Over the 1 m path length of the transmissometer

$$T = e^{-c} \quad \text{or} \quad c = -\ln T. \tag{2}$$

Putting T_m = the measured transmissometer output, $-\ln T_m$ can be compared with Secchi disc depth, z_{sd}. In figure 3 field values of ($-\ln T_m$) at 4 m and 7 m depth are compared with z_{sd}^{-1}. Measurement range bars are only shown for those measurements with some uncertainty. The least squares regression line between ($-\ln T_m$) at 7 m and z_{sd}^{-1} is

$$-\ln T_m = -0.647 + 5.6/z_{sd} \quad (r = 0.96), \tag{3}$$

where r is the correlation coefficient.

The wave-length band of the transmissometer, and hence that applicable to T_m in equation (3), is different from that of the human eye and hence that applicable to z_{sd}. Using the spectral response curves from the Turbidity Monitor's manual the overall spectral response of the

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[1]Full laboratory facilities for calibration of the transmissometer and nephelometer were not available so it was set up in the laboratory as follows: a large bath was partially filled with tap water and for several days the water was pumped out of the bath through a tube containing a 10 µm water filter cartridge and than back into the bath, in order to obtain water which was as clear as possible. With the turbidity monitor immersed in the bath the gains on the transmissometer and nephelometer were then, somewhat arbitrarily, set to 1.00 and 0.5 units respectively. (1.00 is the full scale reading on the maximum range setting for the transmissometer, while 100 is the maximum reading for the nephelometer.)

transmissometer system was obtained and is compared with that of the human eye in figure 4. It can be seen that the transmissometer has a broader wave-length response than the human eye and is far more sensitive in the red and near infra-red region.

It has been found (Højerslev 1986) that for a wide range of turbid waters

$$z_{sd} = B/C_h, \tag{4}$$

where B is a constant approximately equal to 6 and C_h is the attenuation coefficient over the visible wave-length band. Assuming that $\exp(-C_h)$,the transmittance over the visible wave-length band, is proportional to T_m, one can write:

$$T_m = \exp(A).\exp(-C_h)\,,$$

where A is a constant.

Then

$$-\ln T_m = -A + C_h.$$

Substituting for C_h from equation (4), this becomes:

$$-\ln T_m = -A + B/z_{sd}\,.$$

Comparing this with equation (3) gives: A = 0.647 and B = 5.6, so that:

$$z_{sd} = 5.6/C_h, \tag{5(a)}$$

and

$$C_h = 0.647 - \ln T_m. \tag{5(b)}$$

Results for C_h were obtained using equation (5(b)).

2.1.2 Nephelometer

The spectral response of the nephelometer system, which measures scattering at 90°, is shown on figure 5, with and without a 6 cm path-length through pure water included. (6 cm is approximately the distance light would travel from the light source to the nephelometer sensor.) It can be seen that the nephelometer responds primarily in the near-infra-red. The nephelometer output, N, is simply a measure of relative scattering strength as found by this particular instrument. No attempt was made for the work reported here to relate N quantitatively to, say, the ratio of incident to scattered light or to particle concentration.

Depths for the Secchi disc and Turbidity Monitor readings were measured from tapes marked off at one meter lengths on their suspension ropes, with the additional use of a wire-angle meter when the ropes were not vertical.

2.2 Salinity and temperature measurements

Salinity and temperature profiles were obtained with an internally recording Neil Brown Smart CTD system. Its calibration was checked with surface underway bucket samples and with samples obtained on each cast with a single Nansen bottle attached 1 m above the CTD when the CTD was at its maximum depth. After each cast the CTD data were output to a floppy disk on a Deltacom XT Turbo portable computer.

2.3 Suspended sediment sampling

Water samples (usually 250 mL) from the underway bucket and from the subsurface Nansen bottle were also filtered through 0.8 μm Millipore filters to obtain samples of suspended particles. These were stored in a dessicator in the ships' refrigerator. Analysis of these samples is to be published separately.

3. RESULTS

3.1 Secchi disc depths

Secchi disc depths, z_{sd}, for the February oceanographic cruise are displayed in figure 6. They vary between 3 and 4 m except close inshore in Newcastle Bay, on the eastern side of Cape York Peninsula, where a value of 2.5 m was found. As can be seen by comparing figures 6 and 7, Secchi disc depths for the March cruise were generally larger and more variable. The waters west of the Warrior Reefs were still highly turbid; but those in the Great North East Channel were clearer than they had been in February.

Part of the reason for the change between February and March may be associated with the different wind regimes near the times of the two cruises. Hourly measurements from Thursday Island for daylight hours, with some gaps in the data, are available from the Bureau of Meteorology. For the three days prior to the February measurements, winds were from the north-west at 20 to 30 kn, dropping back to 10 to 20 kn during the measurement period (see figure 8). For the four days prior to

the March measurements figure 9 shows that winds were from the south-east at only 0 to 14 kn, but then increased after the first day of the measurement period to 10 to 20 kn. Thus the seas would have been considerably rougher immediately before the February measurements.

The two values of 13 m for z_{sd} near 10°30'S (see figure 7) were taken on the first day of measurements of the March cruise. On the last day of measurements the low Secchi disc depth values west of the Warrior Reefs were obtained from HMAS Launceston, which then passed southward through the area in which the 13 m values had been obtained, but no changes in ocean colour were observed. This implies either that the increased winds over the preceding two days had increased turbidity by increased entrainment of seafloor sediment, or that the highly turbid water from west of the Warrior Reefs had moved southward. In either case turbidity values were not everywhere constant over the four day measurement period.

3.2 Temperature and salinity regimes

In February, XBT's and two CTD profiles were taken by HMAS Cook. (One CTD profile was taken in the Great North East Channel at station 7B and the other in the Adolphus Channel.) They showed that stratification of the water column was weak or entirely absent at that time. From the two CTD profiles salinity at both locations was found to be close to 34.9 psu throughout the water-column.

During the March oceanographic cruise there were significant variations in salinity. The surface salinity variation is shown in figure 10 and low values can be seen off the mouths of the Fly River and west of the Warrior Reefs, with high values in the Adolphus Channel, and intermediate values in the Great North East Channel. Near-bottom salinities are shown on figure 11. In this case high salinity Coral Sea water is intruding into the area along 9°S near station 16, but at a depth greater than the bottom-depth of most of the Torres Strait region. Low and high salinities are again found west of the Warrior Reefs and in the Adolphus Channel, respectively. Sea-surface temperature variations were small, (of order 0.5°C) varying as much with time as with position.

3.3 Attenuation coefficient and nephelometer profiles

A scatter diagram of attenuation coefficient, C_h, versus the nephelometer output, N, is presented in figure 12, using data from both oceanographic cruises. Measurement ranges are shown for two stations where it varied markedly. The attenuation coefficient is the sum of the absorption and total scattering coefficients while the nephelometer responds to scattering at 90° to the light beam. The total scattering coefficient is dominated by scattering at small angles to the incident beam. For a given particle population, points on a C_h versus N plot should cluster about a single curve. This is indeed the case up to $N \approx 3$ or $C_h \approx 1.75\ m^{-1}$ (equivalent, near the surface, to a Secchi disc depth of 3.2 m) but at higher values of N or C_h (more turbid waters) the spread of the points increases, with some but not all the samples from stations 9A and 9B of the February cruise having higher than typical values for 90° scattering. Scanning electron microscope examination of suspended particle samples did not indicate any obvious differences between samples from 9A or 9B and those from other locations; nevertheless there must be some differences in the particles.

Representative attenuation coefficient and nephelometer profiles are displayed in figures 13(a) and (b), respectively, for the February oceanographic cruise and figures 14(a) and (b), respectively, for the March cruise. Figures 14(c) and (d) show salinity and temperature profiles, respectively, for

the March cruise. Temperature and salinity stratification are marked for station 15, off the Fly River; are present at station 8; and are weakly apparent at station 20. Stations 8 and 20 were towards the northern end of the Great North East Channel (see figure 2). Stratification at stations 8 and 20 can also be seen in turbidity. The transmissometer did not go sufficiently deep at station 15 to ascertain if turbidity rose in the lower layers but the amount of suspended sediment found in a near-bottom water sample was much larger than that found in a near surface one. At other locations temperature and salinity are approximately constant with depth and at these places turbidity is also approximately uniform with depth, except in the more turbid waters ($C_h > 1.0\ m^{-1}$) (eg stations 21B and 23B in figure 14; stations 7C and 9B in figure 13) where C_h and N vary substantially, and generally increase, with depth. In general then, when the water is stratified in terms of temperature and/or salinity the lower layer is more turbid than the upper one, otherwise turbidity is uniform with depth except in very turbid waters where turbidity generally increases towards the bottom, but can also have mid-depth maxima.

4. DISCUSSION

4.1 Dependence of turbidity on wind-speed and bottom depth

The decreases in turbidity found between the February and March cruises may have been due, at least in part, to the observed reduction in wind speed, and a consequent reduction of the entrainment of seafloor sediment into the water column. To test the influence of wind speed on turbidity a number of regression relations have been examined. The regression between Secchi disc depth, z_{sd}, and W^{-1}, where W is the wind-speed averaged over the previous 24 hours (using linear interpolation when data were absent) for all stations, except 10A in February and 15 and 16 in March, (ie those in the special locations of inshore Newcastle Bay and off the Fly River mouths) gave a correlation coefficient, r, of 0.48 (with a 90% confidence interval of 0.71 to 0.16). The number of points available is 24. By comparison Walker and O'Donnell (1981) found a correlation coefficient of 0.73 between attenuation coefficient (which was inversely proportional to z_{sd}) and wind-speed-run over the previous 24 hours, at one station in Cleveland Bay, near Townsville, which was sampled weekly for one year. Water depth at this station was 10 m. For the Torres Strait data presented here, regression of z_{sd} against water depth, z, gave r = 0.60 (with a 90% confidence interval 0.32 to 0.78). In the Townsville to Low Islets region of the Great Barrier Reef lagoon Walker (1981) found a correlation coefficient of 0.98 between the average of all Secchi disc depth measurements, at any one station, and water depth, with water depth ranging from 4 m to 43 m. Multiple linear regression of z_{sd} against z and W^{-1}, with z and z_{sd} in metres and W in knots gave, for the Torres Strait data of this report:

$$z_{sd} = -7.98 + 0.30\,z + 107.0/W, \tag{6}$$

with

$$r = 0.84 \text{ (or } r^2 = 0.71),$$

(See figure 15.) (The 90% confidence interval for r in this case is 0.70 to 0.92.) That is, a linear regression of Secchi disc depth against water depth and (wind speed)$^{-1}$ "explained" 71% of the variability in turbidity. The rms difference between the measured and predicted z_{sd} is 1.7 m. Factors not included in this equation are the strength of local tidal currents (which are known to be strong (Wolanski, 1983)), the advection of turbid water masses from other regions, and variations in seafloor sediment characteristics. The data in Torres Strait, for varying locations and wind-speeds, have had to be combined because of the sparsity of data but it is interesting that the multiple regression equation's correlation coefficient is intermedi‹ ‹e between those from Walker and O'Donnell (1981) and Walker (1981).

4.2 A link between turbidity and salinity

If the sediment in suspension in Torres Strait comes from rivers, especially those of Papua New Guinea, there is likely to be a significant correlation between turbidity and salinity. To examine this possibility scatter diagrams were constructed of Secchi disc depth versus surface salinity, and of near-bottom salinity versus near-bottom attenuation coefficient. These are shown in figures 16 and 17, respectively. The two turbidity/salinity pairs obtained in the February oceanographic cruise are very similar to each other, but the situation found on the March cruise is very different. There appear to be 3 regimes in March. Low salinity, clear water is found near the surface off the Fly River mouths; high salinity, turbid waters are found in the Adolphus Channel; and elsewhere there is a significant correlation between salinity and turbidity in both near-surface and near-bottom waters, with turbidity increasing as salinity decreases, suggesting that mixing is taking place between a brackish, turbid water mass and clearer sea-water. The origin of this turbid, low salinity water mass is uncertain.

The relatively clear and brackish water found in March near the mouths of the Fly River had a quite different colour from that found elsewhere and looked like black tea (stations 15 and 16). The more turbid, brackish waters west of the Warrior Reefs were a chalky pastel green colour. In March 1988, therefore, the latter low-salinity waters were not derived directly from the Fly River or the rivers flowing into the Gulf of Papua.

Rainfall near the times of the two oceanographic cruises were similar as can be seen from the data from Thursday Island shown on figure 18. The differences in salinity between February and March cannot, apparently, be explained by local rainfall.

Wolanski et al (1984) found a different situation in November/December 1979, November 1981, April/May 1982 and October 1982 (their figures 3 and 4). In the first three cases the 34.0 psu contour ran north-east to south west through 10°S, 143°E, with lower salinities to its north-west. Salinity decreased towards the Gulf of Papua in the first two cases and in October 1982. (In April/May 1982 no data were obtained north of 9°S.) In October 1982 a tongue of low salinity water appeared to be intruding south-westwards along the axis of the Warrior Reefs from the Gulf of Papua. The low salinity waters in 1979 and 1981 in the Gulf of Papua are described, as turbid. Wolanski et al (1984) also discuss a Landsat image of November 1980 which shows a less turbid tongue of water intruding down the Great North East Channel from the north-east, and highly turbid waters west of the Warrior Reefs. It appears that in this case the low salinity waters arising from river input to the Gulf of Papua have low turbidity. (All the observations on turbidity in this reference are purely qualitative.)

There is an alternative source for the low salinity, turbid water mass. Rochford (1966) found a low salinity water mass in August 1964 off the south-west coast of West Irian. In March/April 1958 he found a similar water mass just west of Torres Strait (see his figure 1). Rochford thought that a low salinity water mass is formed: "in the coastal water of West Irian during the monsoonal rains of December to January (Wyrtki 1961) and is driven by the north-west monsoon into the region north of the Gulf of Carpentaria by March. During the period March to August, the increasing strength of the South-East Trades drives this low salinity water back into the position found in August 1964." Plates 11 to 14 of Wyrtki (1961) show a low salinity region off the southern coast of West Irian (or Irian Jaya).

Wind-speed data have been obtained from Thursday Island for September 1987 to March 1988. The north-west monsoon season was unusually short. Winds were generally from the south-east in this period, but there were periods of north-westerlies from 20 December 1987 to 3 January 1988, for a few days after 7 January, and from early February to early March 1988. (See Harris, 1989, figure 18.) The north-westerlies in February could have moved a low salinity water mass into the Torres Strait area from further west. The average wind speed for February at Thursday Island was approximately 8 ms^{-1}. Assuming the surface current set up by this wind has 2% of the wind's magnitude (Pond and Pickard, 1983) and that this wind blows for 30 days, a water mass would be transported approximately 400 km or 4^{o} longitude to the east, say from $138^{o}30'$E to $142^{o}30'$E, which is a distance of the right order of magnitude.

Alternatively the more persistent South-East Trades could have moved low salinity waters from the Gulf of Papua into the Torres Strait area over the previous months. In either case any low salinity water mass formed in or advected into a shallow coastal area, and having a reasonable residence time there, would be expected to have lower salinity and higher turbidity in its close inshore section, than further off shore where there would be more mixing with ocean waters. While such a water mass was moved around it could well retain for several months a good correlation between turbidity and salinity.

The writer has also examined Landsat images of the study area for September 1984 and December 1986. Both show turbid waters occurring west of the Warrior Reefs and in the region 10^{o}S to $10^{o}30'$S around 143^{o}E, but the December 86 image also shows the turbid waters intruding halfway across the Great North East Channel. Immediately to the west of Torres Strait, west of 142^{o}E, there is frequently an area of highly turbid water between the New Guinea coast and $9^{o}30'$S. An algorithm relating in-situ to satellite-sensed turbidity needs to be developed before quantitative deductions can be made from satellite imagery, and this is an area of on-going research.

4.3 Underwater visibility ranges

Using the Secchi disc and attenuation coefficient data it is possible to estimate underwater visibility ranges. From Williams (1970), underwater visibility range, V, is often estimated as $3.5/C_h$. Determining that 3.5 is the correct constant to use in Torres Strait would require field trials with divers. A visibility scale is included in figures 13 and 14. In February V was less than 3 m throughout the area, while in March it was still less than 3 m in the Adolphus Channel (except at station 21D) and west of the Warrior Reefs, but was above 3 m at other locations (except near the bottom at station 20).

Near-surface underwater visibility range, V_s, can be related to Secchi disc depth, z_{sd}, via the above relation and equation (5(a)) of Section 2 to give:

$$V_s = 0.63\, z_{sd} . \tag{7}$$

Equation (7) together with equation (6) between Secchi disc depth, water depth z, and W^{-1}, where W is wind-speed averaged over the previous 24 hours, can be used to estimate underwater visibility range:

$$V_s = -5.03 + 0.19\, z + 67.4/W . \tag{8}$$

Provided the water column is unstratified or only weakly stratified, for $V_s > 3.5$ m (ie for $C_h < 1\ m^{-1}$ or $z_{sd} > 5.6$ m or $z > 44.9 - 355/W$), equation (8) can be used for the whole water column .

4.4 The nature of the suspended sediment

Samples of the suspended sediment have been examined using a Scanning Electron Microscope. This phase of the work will be described more fully elsewhere, but the dominant contribution is from clay particles, with, in decreasing order of importance, calcium carbonate fragments of biological origin and living diatoms. The source of the turbidity is not known and is of some interest because, given the strong tidal currents and resultant turbulent mixing in Torres Strait, all fine material in the area should have been dispersed out of it. The continuing high turbidity requires either that suspended sediment be continuously brought into the strait, or that there is a source of fine sediment within the area which is still being actively eroded.

5. CONCLUSIONS

The conclusions given here are drawn from data obtained in February/March (the wet season) 1988 and data from other years are required to check their generality. Further work is required to fully understand turbidity variations in eastern Torres Strait, especially at other times of the year.

Turbidity is highly variable, with 71% of its variability describable by a multiple linear regression with water depth and (wind speed)$^{-1}$. Highly turbid, low salinity water masses are also present which may come from either the Gulf of Papua or the coastal waters of Irian Jaya.

In most cases, the waters in Torres Strait are unstratified or only weakly stratified, in terms of temperature and salinity, except near the northern end of the Great North East Channel. For stations with lower turbidities such that $C_h < 1.0\ m^{-1}$ turbidity is approximately constant with depth at the weakly stratified stations but there is a more turbid, lower layer at the stratified ones. At more turbid locations with $C_h > 1\ m^{-1}$ turbidity generally increases with depth, but at some locations there are midwater maxima.

Underwater visibility ranges are consistently less than 3 m in the Adolphus Channel and west of the Warrior Reefs and are often less than 3 m in the Great North East Channel. Visibility ranges can be estimated from the regression equation:

$$V = -5.03 + 0.19\,z + 67.4/W\,,$$

with a rms accuracy of 1.1 m.

On the instrumental side, it has proved possible to obtain a calibration, at least for eastern Torres Strait, of a transmissometer using concurrent Secchi disc measurements, and thence to obtain attenuation coefficient profiles from the transmissometer and values of near surface attenuation coefficient from standard Secchi disc measurements.

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REFERENCES

No.	Author	Title
1	Harris, P.T.	"Sediments, Bedforms and Bedload Transport Pathways on The Continental Shelf Adjacent to Torres Strait, Australia - Papua New Guinea". **Continental Shelf Res. 8**, pp.979-1003, 1988
2	Harris, P.T., Schneider, P.M. and Baker, E.K.	"Currents, Sedimentation and Sandwave Migration in The Great North East Channel and Adolphus Channel Areas of Torres Strait: Report on Measurements Taken on HMAS 'Cook' cruises, 1988". Ocean Sciences Institute Report No. 28. University of Sydney, p.85, 1988
3	Harris, P.T.	"Sandwave Movement Under Tidal and Wind-Driven Currents in a Shallow Marine Environment: Adolphus Channel, Northeastern Australia". **Continental Shelf Res.** (in press), 1989
4	Højerslev, N.K.	"Visibility of the Sea With Special Reference to the Secchi Disc". **Proc. Soc. Photo-Opt. Instr. Eng. 637**, p.37, 1986
5	Maxwell, W.G.H.	**Atlas of the Great Barrier Reef**, Elsevier, Amsterdam, p.258, 1968
6	Maxwell, W.G.H.	"Sediments of the Great Barrier Reef Province". **Biology and Geology of Coral Reefs, Vol.1**, Geology 1., O.A. Jones and R. Endean (eds). Academic Press, New York, p.410, 1973
7	Pond, S. and Pickard, G.L.	**Introductory Dynamical Oceanography**, Pergamon, Oxford, p.329, 1983
8	Rochford, D.J.	"Some Hydrological Features of the Eastern Arafura Sea and the Gulf of Carpentaria in August 1964". **Aust. J. Mar. Freshwater Res. 17**, pp.31-60, 1966
9	Walker, T.A.	"Dependence of Phytoplankton Chlorophyll on Bottom Resuspension in Cleveland Bay Northern Queensland". **Aust. J. Mar. Freshwater Res. 32**, pp.981-986, 1981

10	Walker, T.A. and O'Donnell, G.	"Observations on Nitrate, Phosphate and Silicate in Cleveland Bay, Northern Queensland". **Aust. J. Mar Freshwater Res. 32, pp.877-887, 1981**
11	Williams, J.	**Optical Properties of the Sea**, U.S. Navy Inst., Annapolis, Maryland, p.124, 1970
12	Wolanski, E.	"Tides on the Northern Great Barrier Reef Continental Shelf". **J. Geophys. Res. 88, pp.5953-5959, 1983**
13	Wolanski, E.	"The Physical Oceanography of Torres Strait". **In Torres Strait Fisheries Seminar**, A.K. Haines, G. C. Williams and D. Coates (editors), Australian Government Printing Service Canberra, ACT, pp.275-291, 1986
14	Wolanski, E. and Ruddick, B.	"Water Circulation and Shelf Waves in the Northern Great Barrier Reef Lagoon". **Aust. J. Mar. Freshwater Res. 32, pp.721-740, 1981**
15	Wolanski, E. and Thomson, R.E.	"Wind-driven Circulation on the Northern Great Barrier Reef Continental Shelf in Summer". **Estuarine, Coastal and Shelf Science 18, pp.271-289, 1984**
16	Wolanski, E., Pickard, G.L. and Jupp, D.L.B.	"River Plumes, Coral Reefs and Mixing in the Gulf of Papua and the Northern Great Barrier Reef". **Estuarine, Coastal and Shelf Science, 18, pp.291-314, 1984**
17	Wolanski, E., Ridd, P. and Inoue, M.	"Currents through Torres Strait". **J. Phys. Oceanogr.18, pp.1535-1545, 1988**
18	Wyrtki, K.	"Scientific Results of Marine Investigations of the South China Sea and the Gulf of Thailand 1959-61". Naga-Report, Vol.2. (Scripps Institution of Oceanography), p.195, 1961

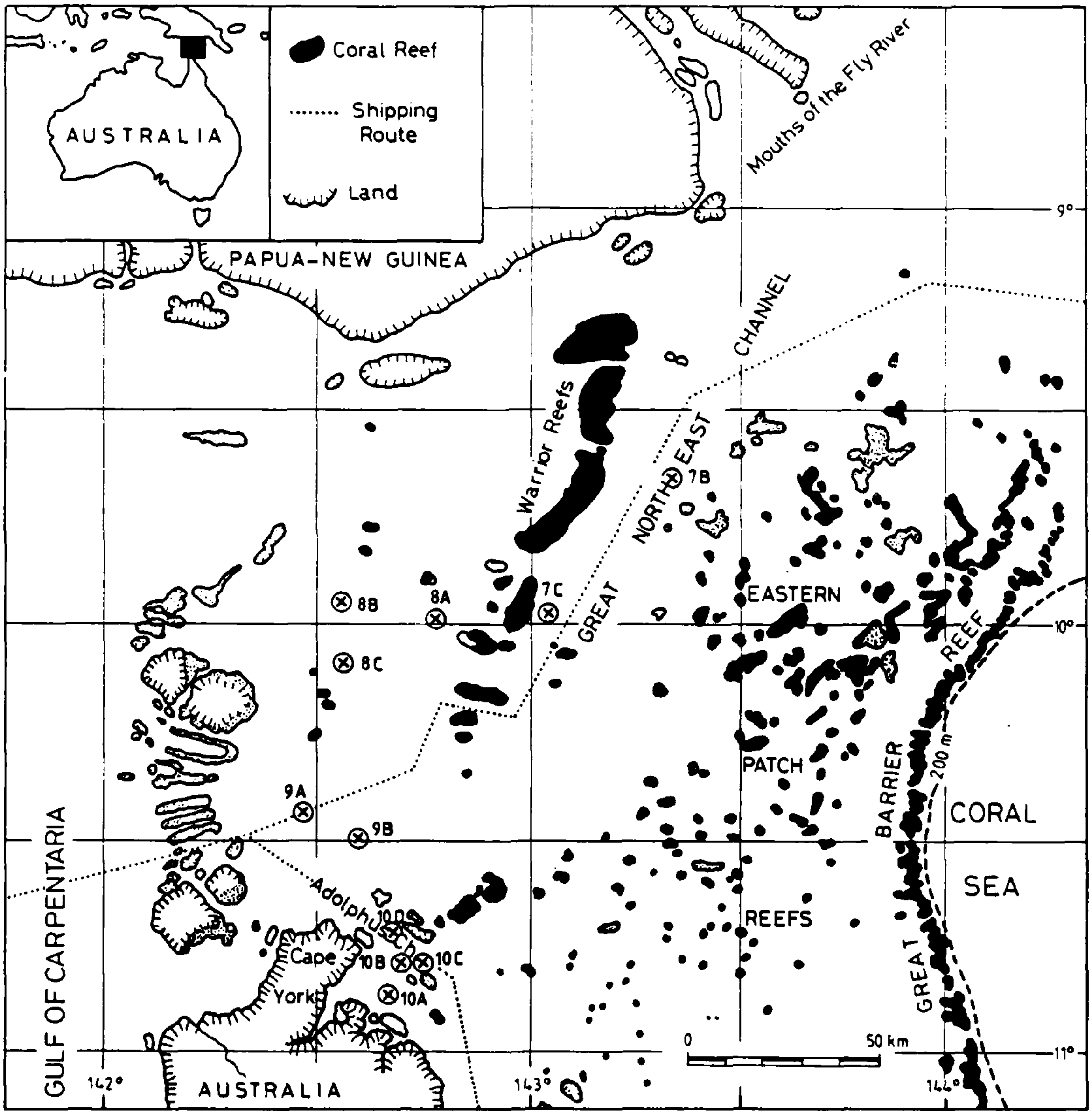


Figure 1. Station positions in Torres Strait on February 1988 cruise. Locations of main shipping routes, coral reefs and the 200 m isobath are shown

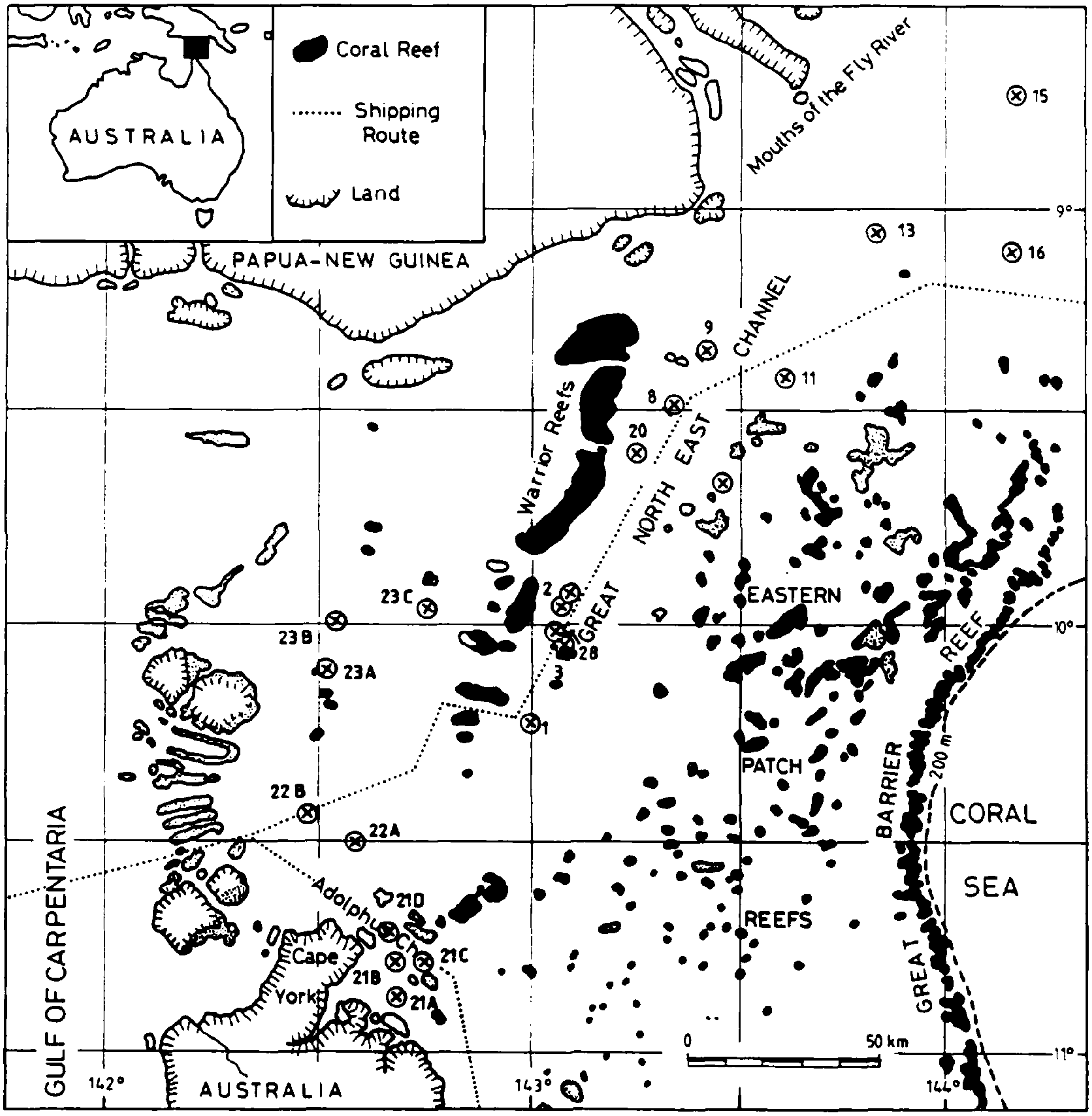


Figure 2. Station positions in Torres Strait on March 1988 cruise. Locations of main shipping routes, coral reefs and the 200 m isobath are shown

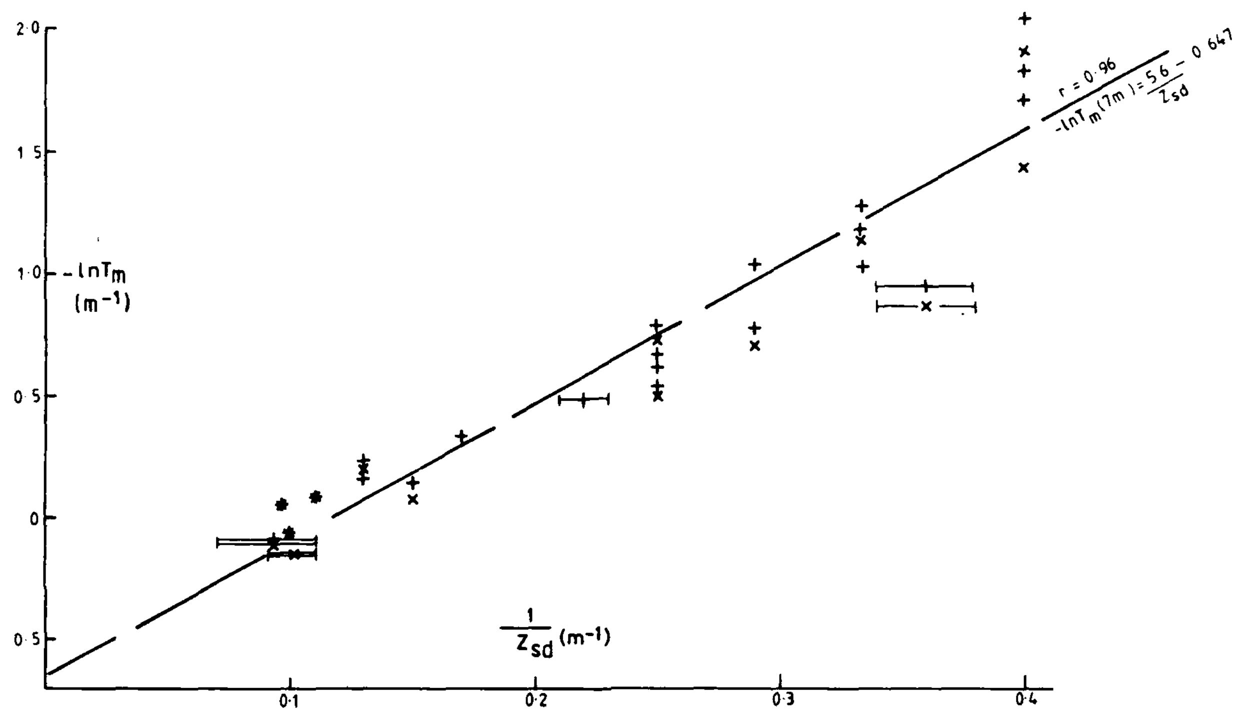


Figure 5. Calibration of transmissometer against Secchi disc depth for transmissometer at 4 m, x; 7 m + , ⊢⊣ measurement range

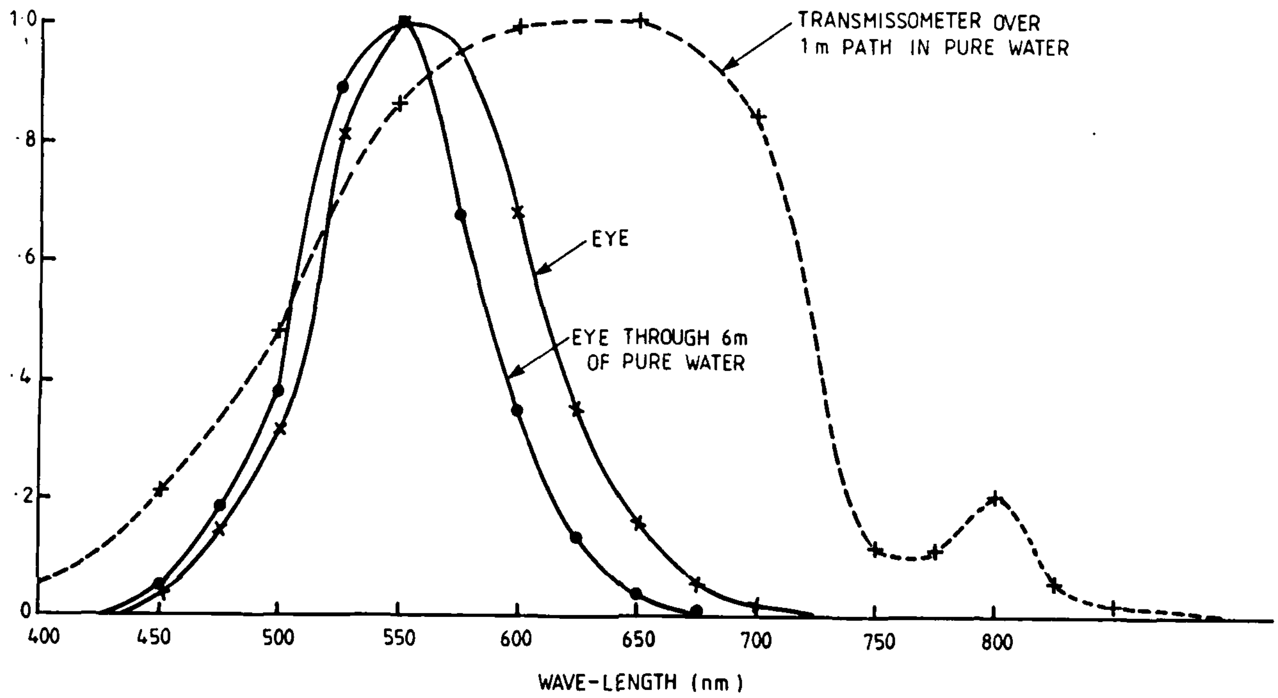


Figure 4. Spectral response of transmissometer and of a typical human eye

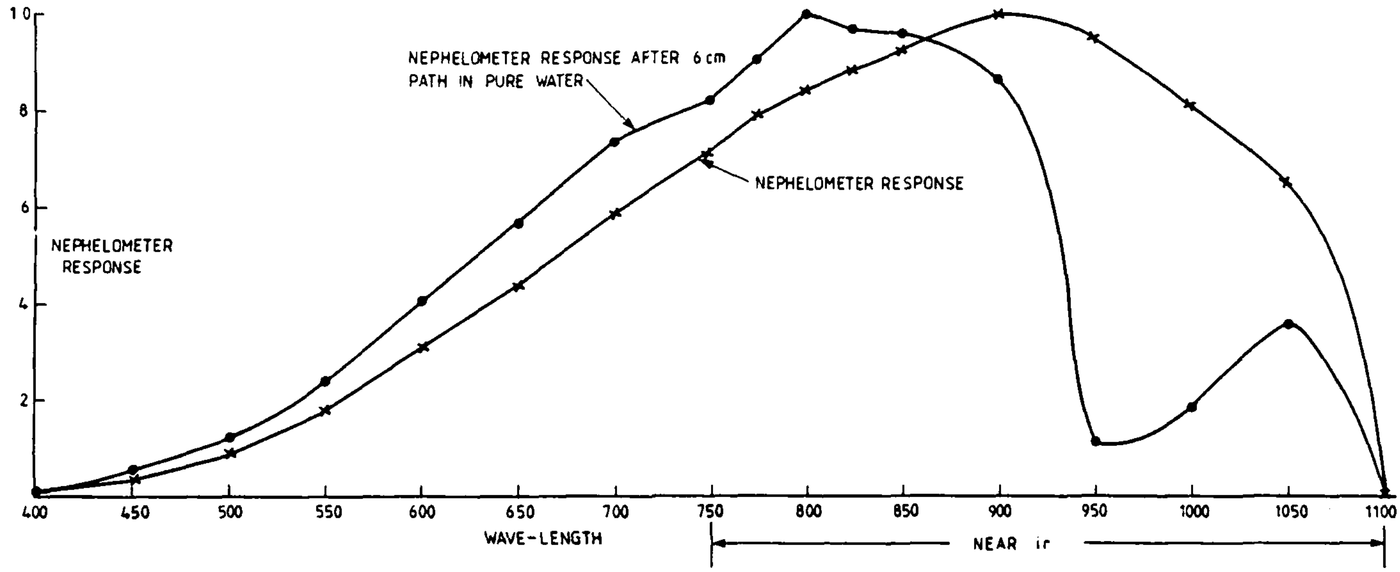


Figure 5. Spectral response of nephelometer

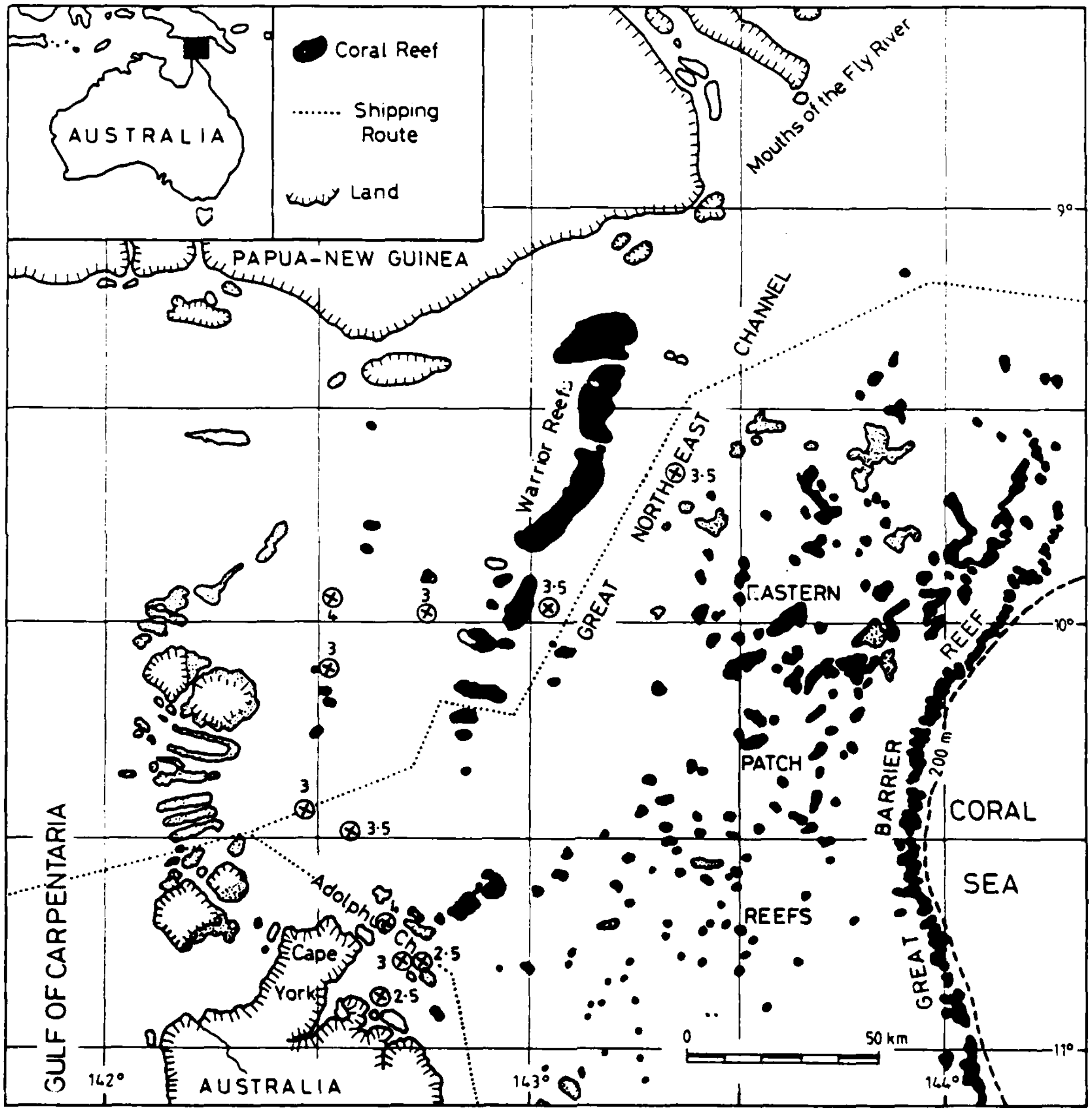


Figure 6. Secchi disc depths (in metres) on February 1988 cruise

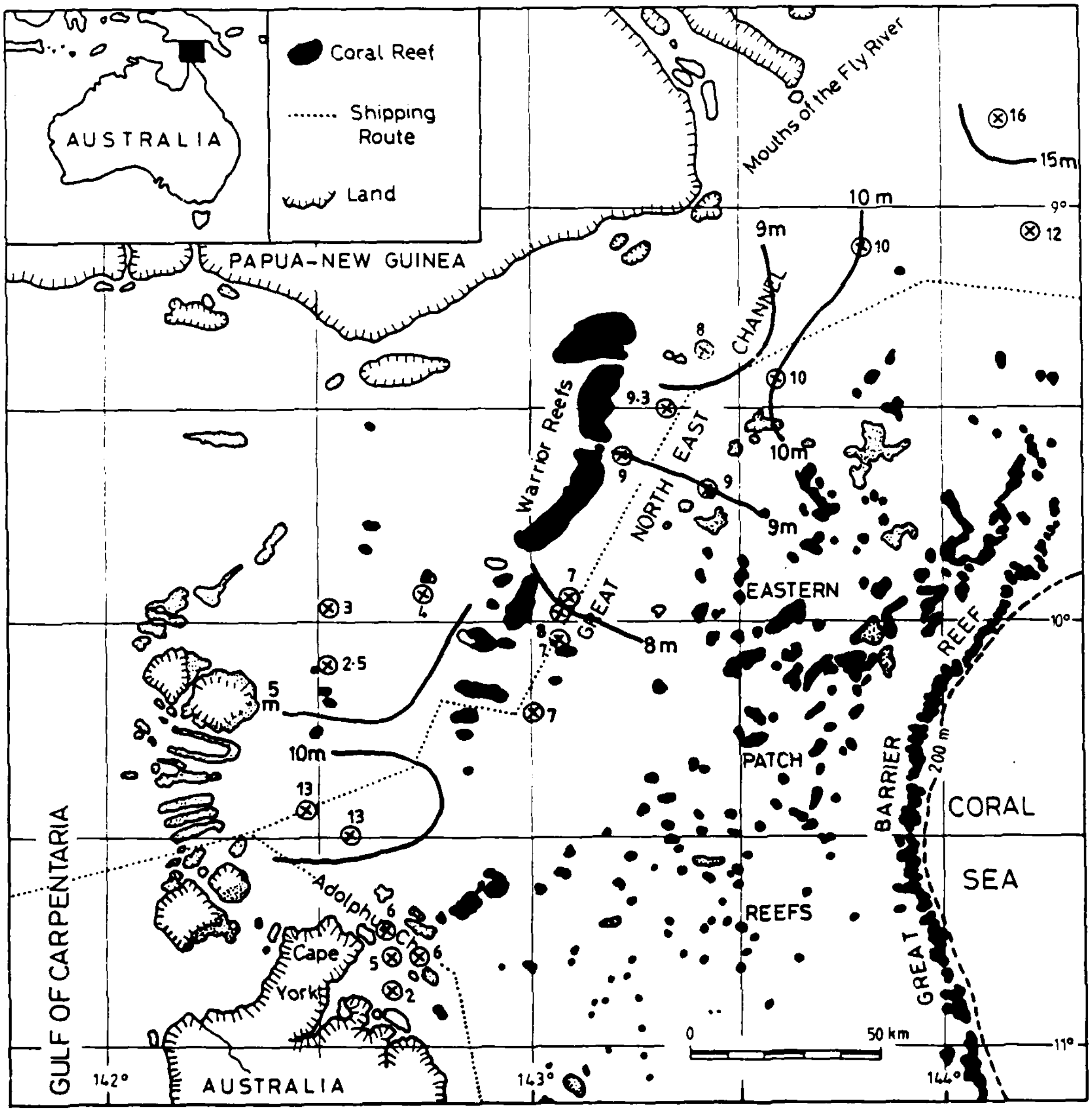


Figure 7. **Secchi disc depths (m) on March 1988 cruise. Locations of main shipping routes, coral reefs and the 200 m isobath are shown. In cases where transmissometer but not Secchi disc observations were obtained (e.g. at night) the latter have been inferred from equation (3)**

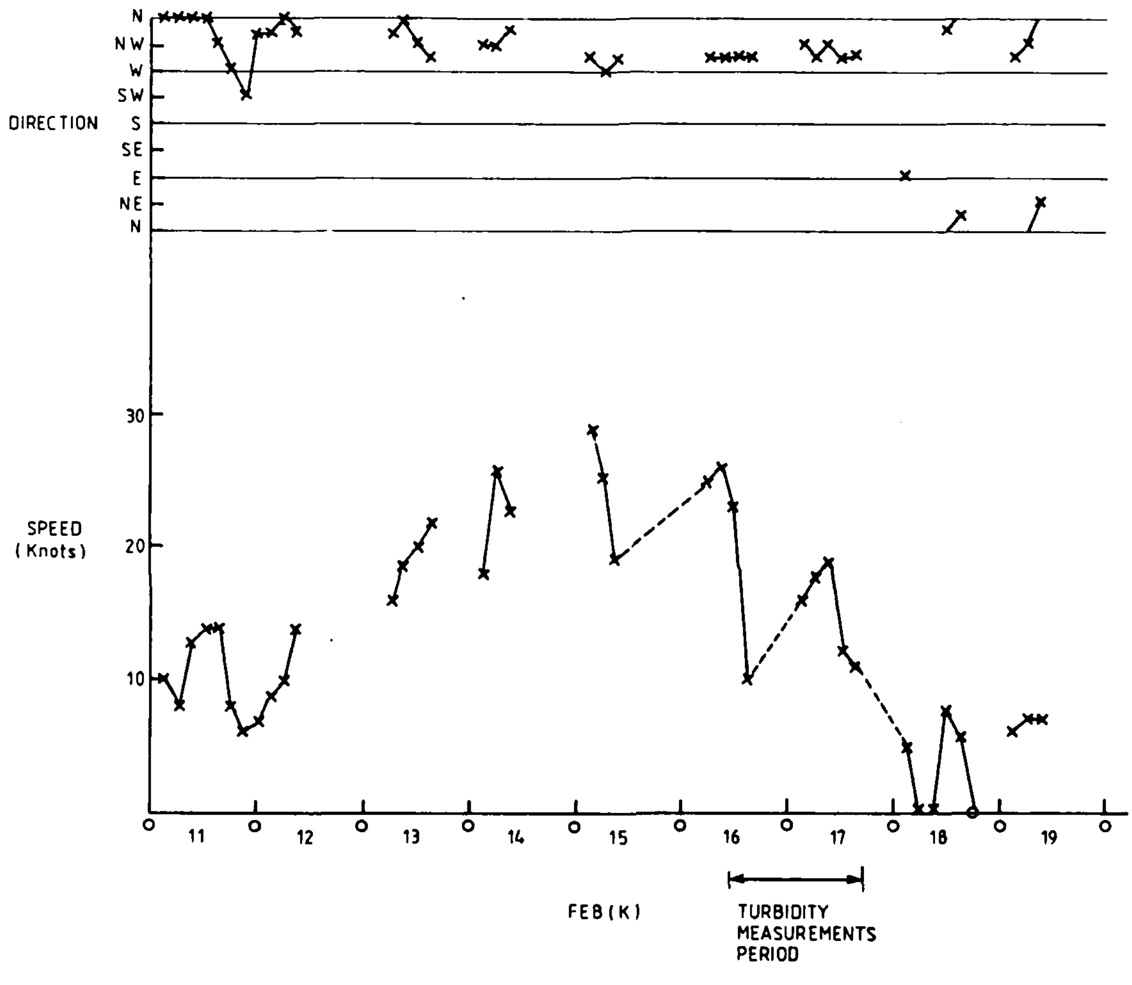


Figure 8. Wind speed and direction from Thursday Island for February 1988

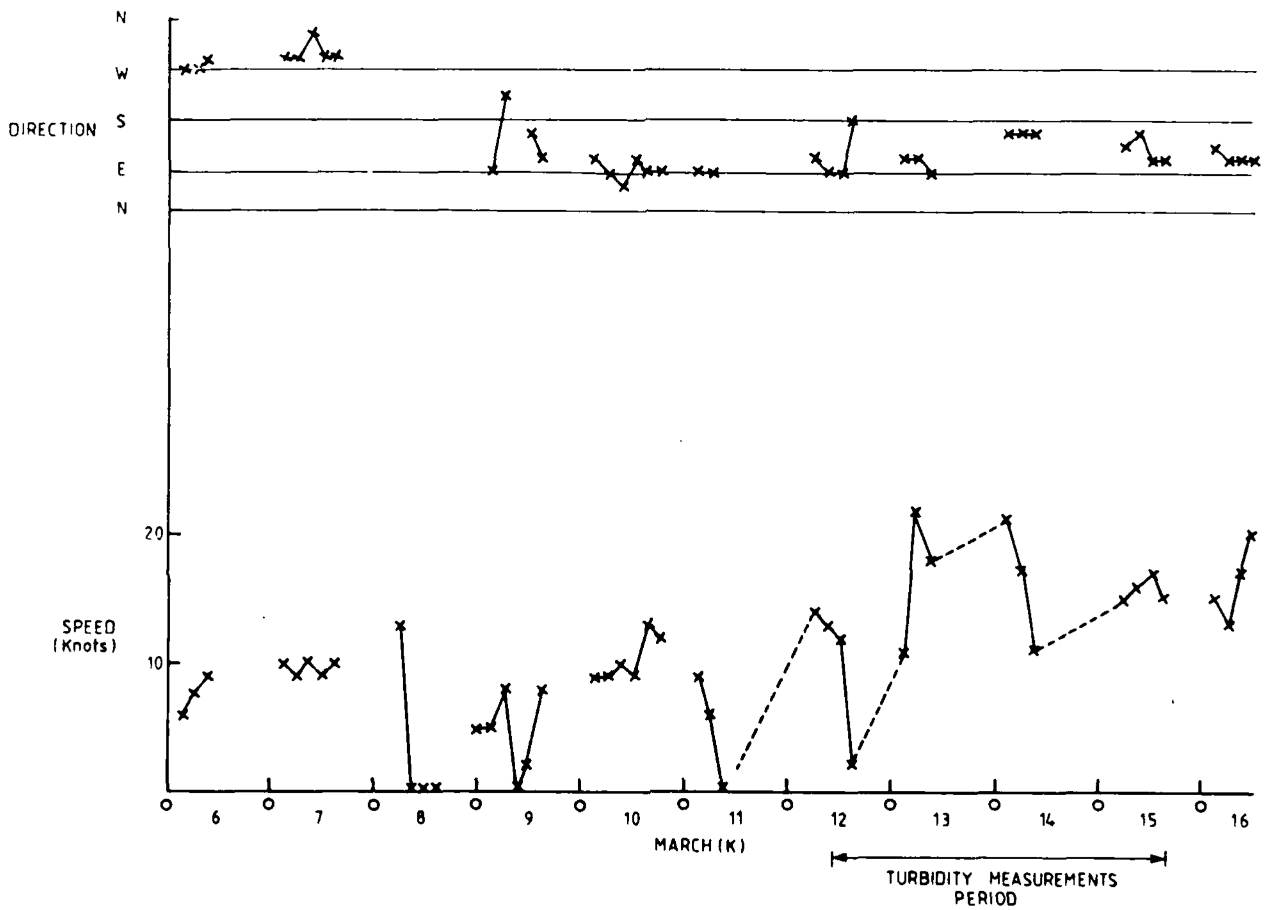


Figure 9. Wind speed and direction from Thursday Island for March 1988

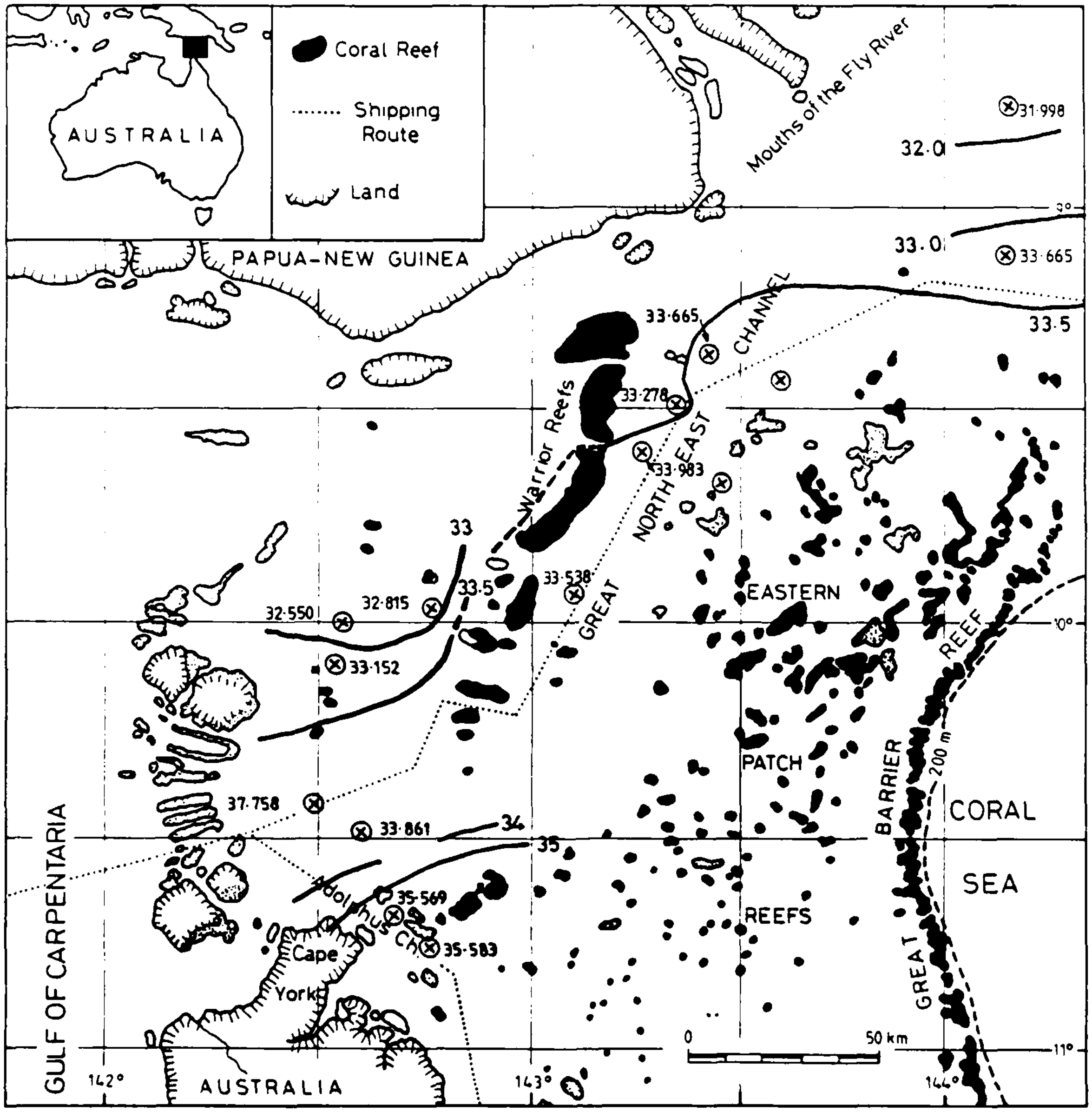


Figure 10. Near surface salinity (1.5 m depth) on March 1988 cruise. Locations of main shipping routes, coral reefs and the 200 m isobaths are shown

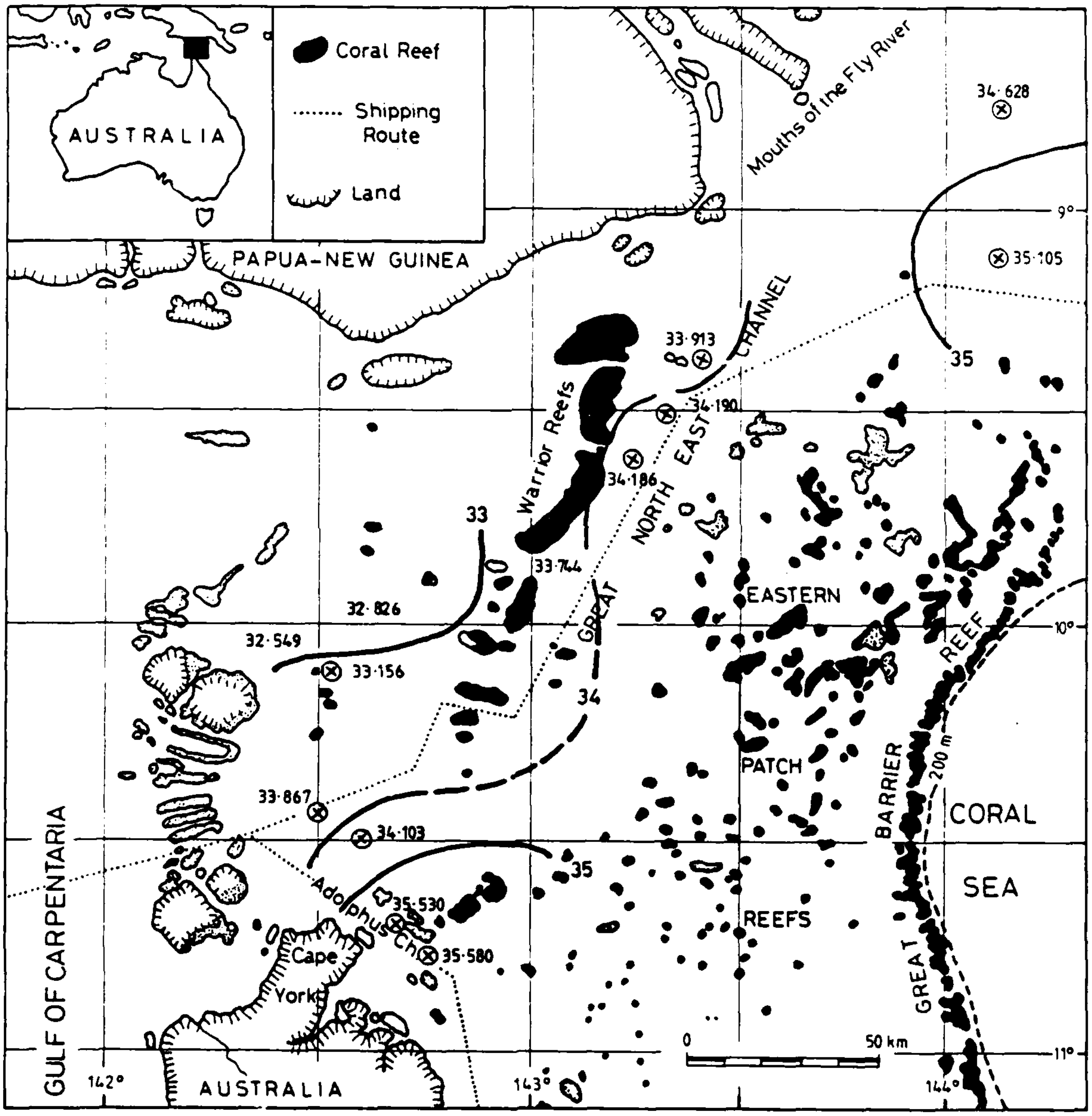


Figure 11. Near bottom salinity on March 1988 cruise. Locations of main shipping routes, coral reefs and the 200 m isobaths are shown

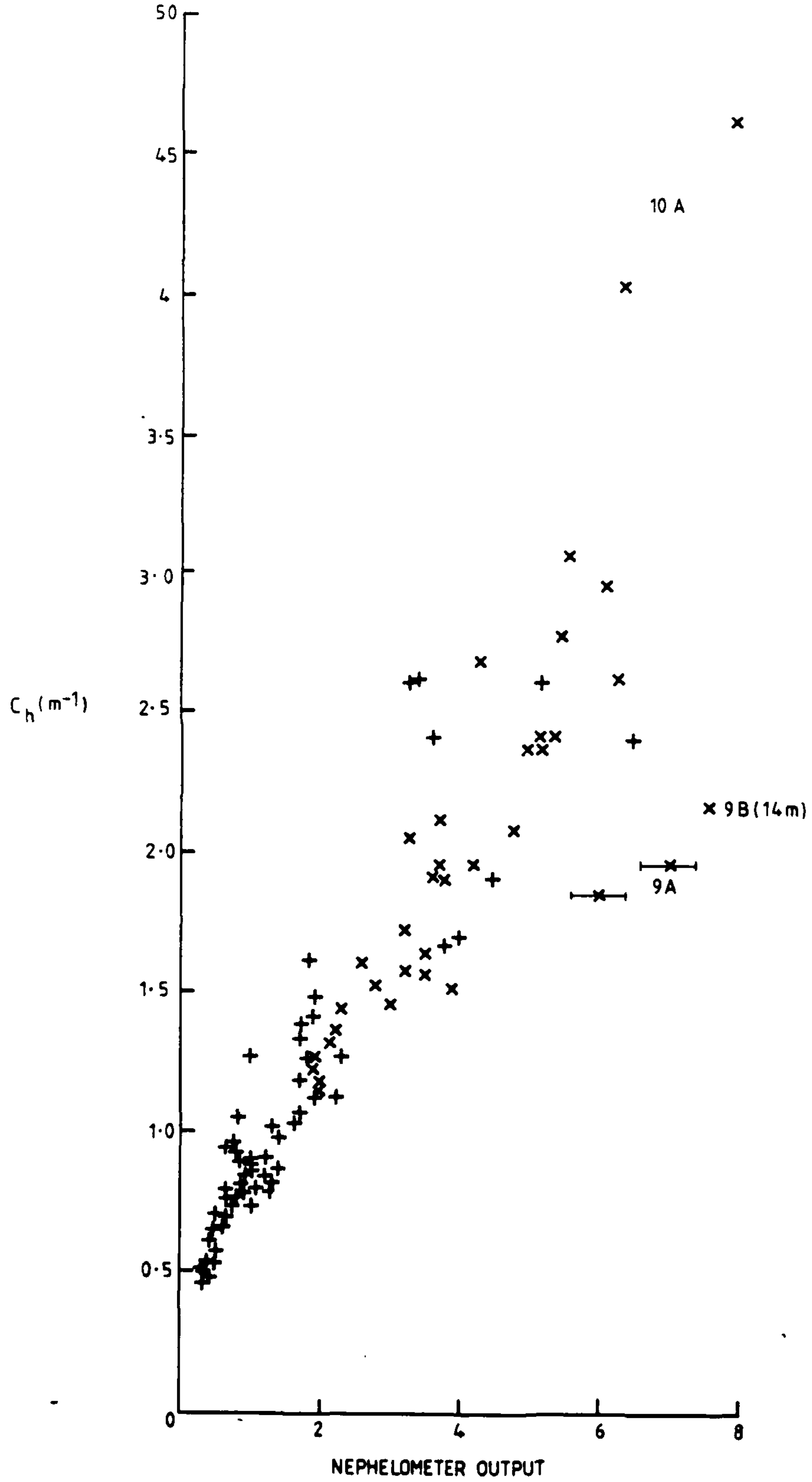
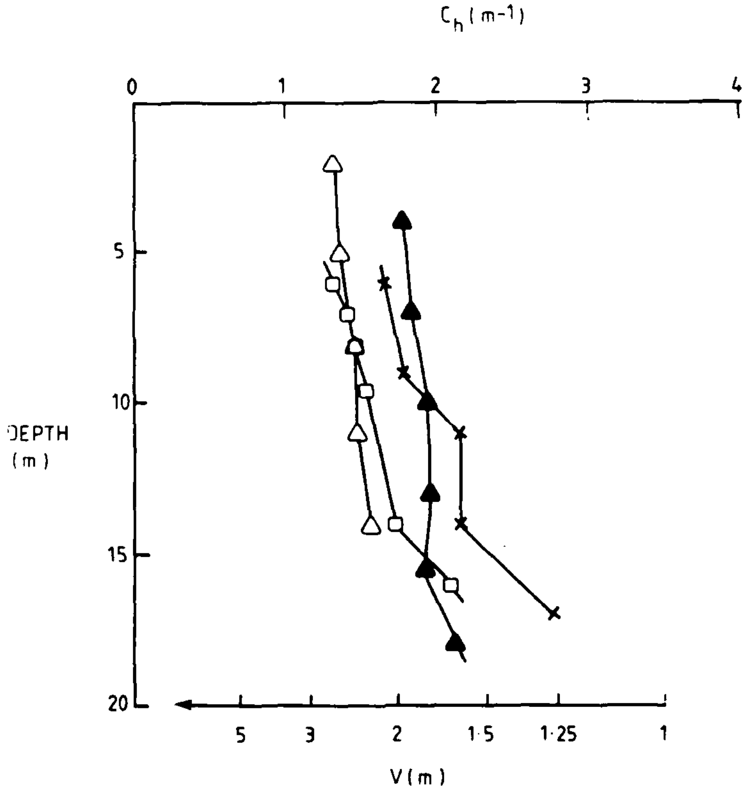
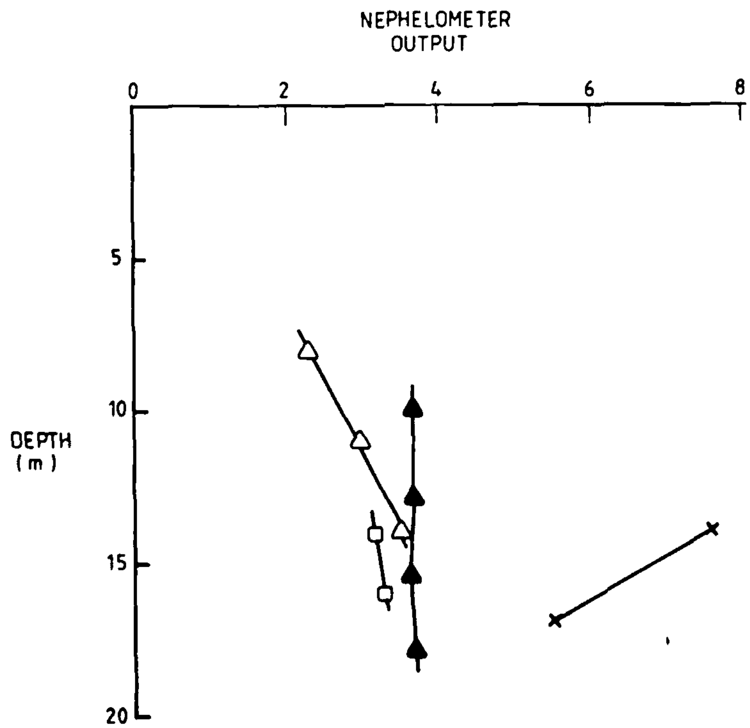


Figure 12. Comparison between nephelometer and transmissometer, x February, + March 1988. Numbers on figures refer to stations. ⊢—⊣ is measurements range



(a)



(b)

Figure 13. Profiles of (a) attenuation coefficient and (b) nephelometer output from the February 1988 cruise at stations: 7C,□; 8C,Δ; 9B, x; 10B,▲. V is visibility range (= 3.5/C_h), and is discussed in Section 4

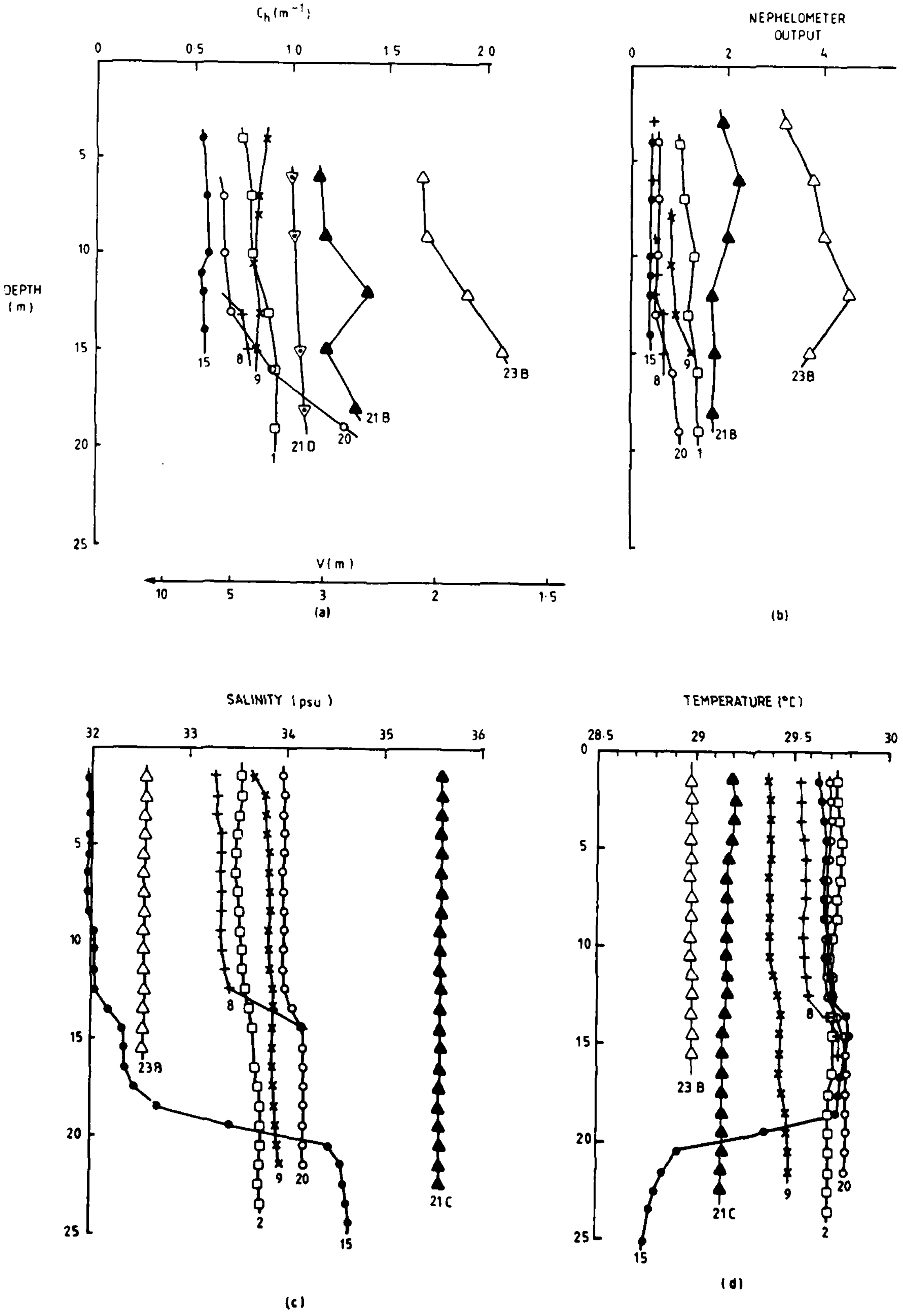


Figure 14. Profiles of (a) attenuation coefficient (b) nephelometer output (c) salinity and (d) temperature for the March 1988 cruise at stations: 1 or 2□; 8 +; 9 x; 15 •; 20 o; 21B or C▲; 21D▽; 23B△. V is visibility range (= $3.5/C_h$) and is discussed in Section 4. (For sake of clarity only C_h data are shown at 21D)

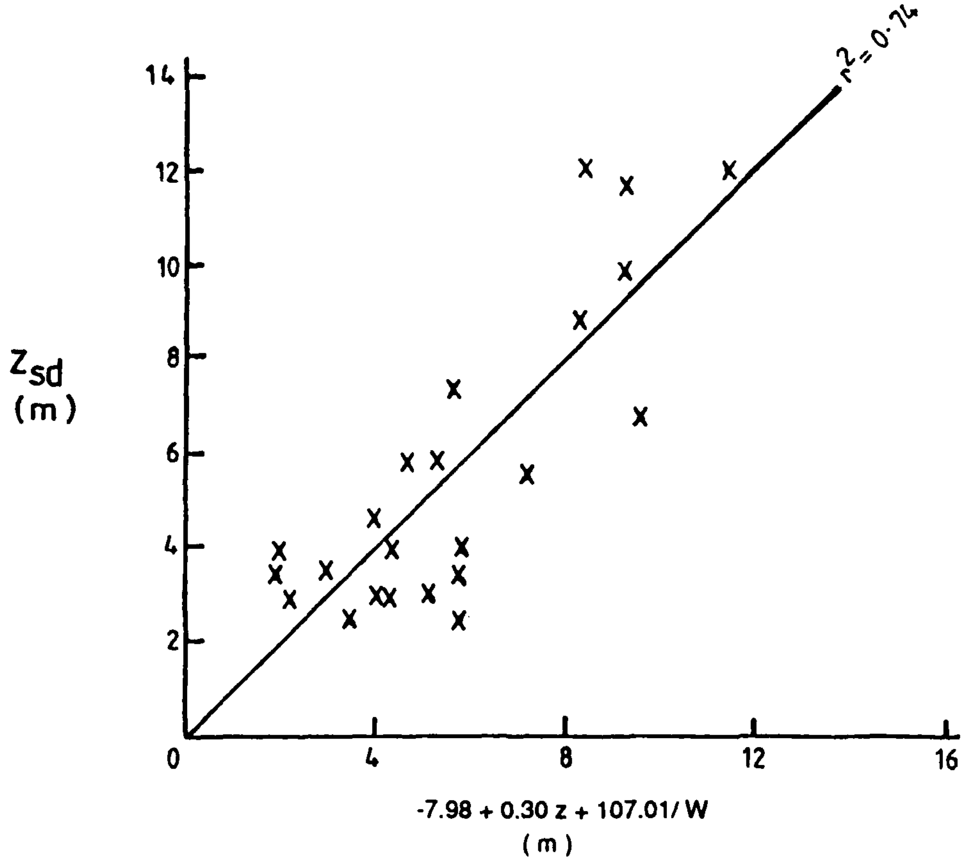


Figure 15. Comparison between measured Secchi disc values and those from regression equation

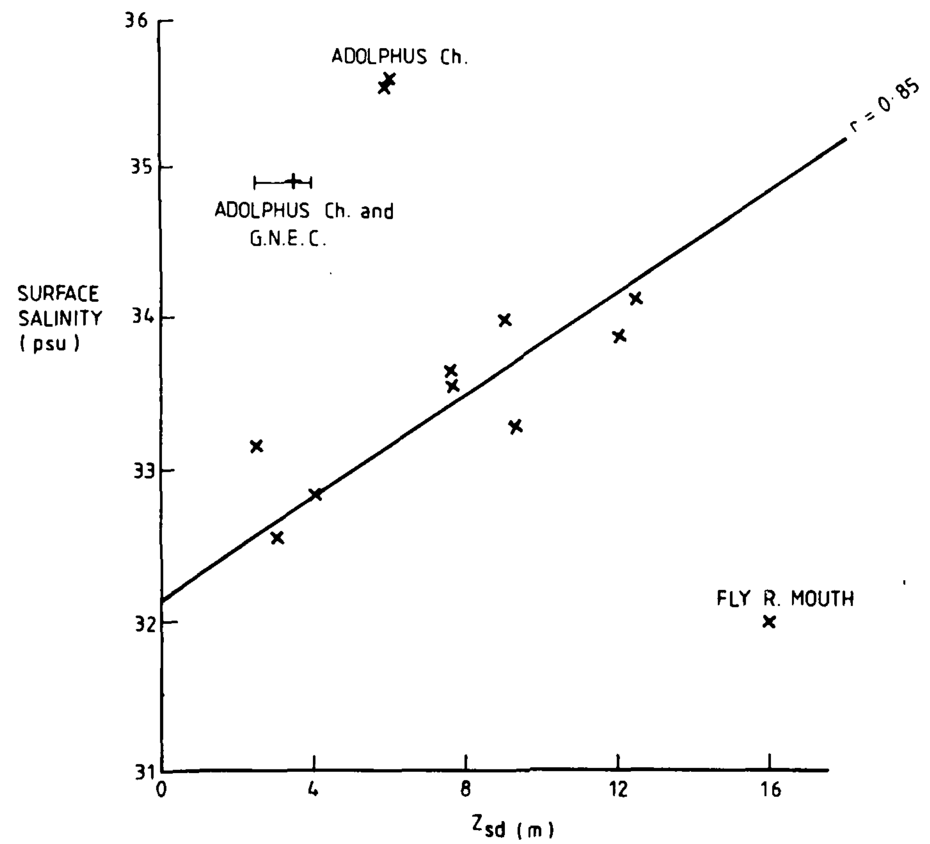


Figure 16. Surface salinity versus Secchi disc depth for February, +; March, x, 1988

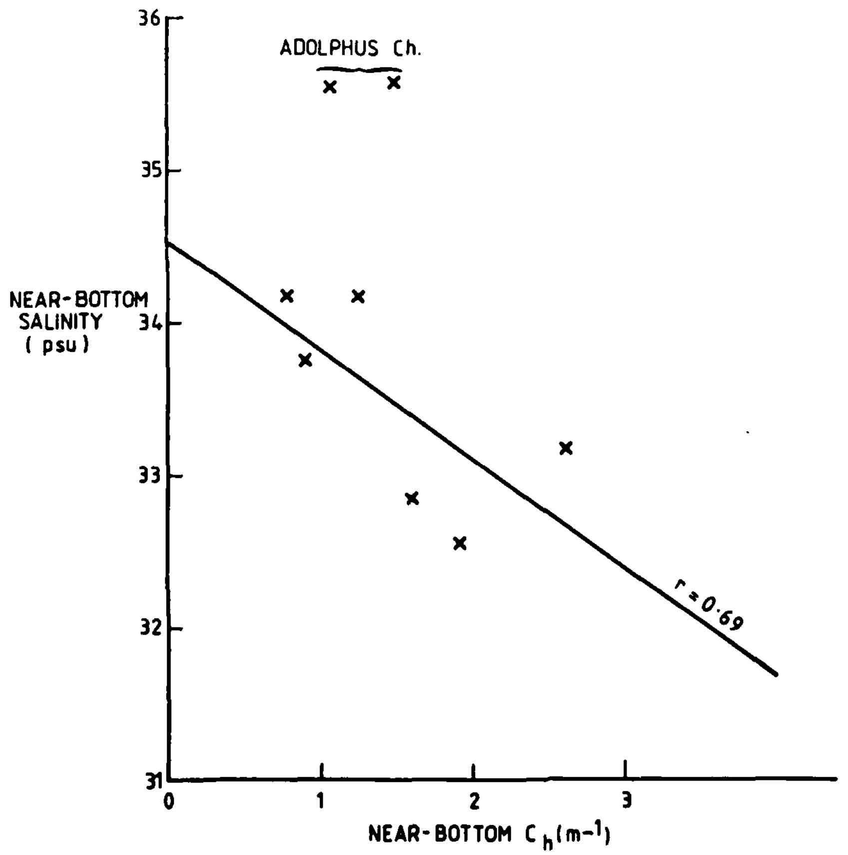


Figure 17. Near-bottom salinity versus near bottom attenuation coefficient for March 1988

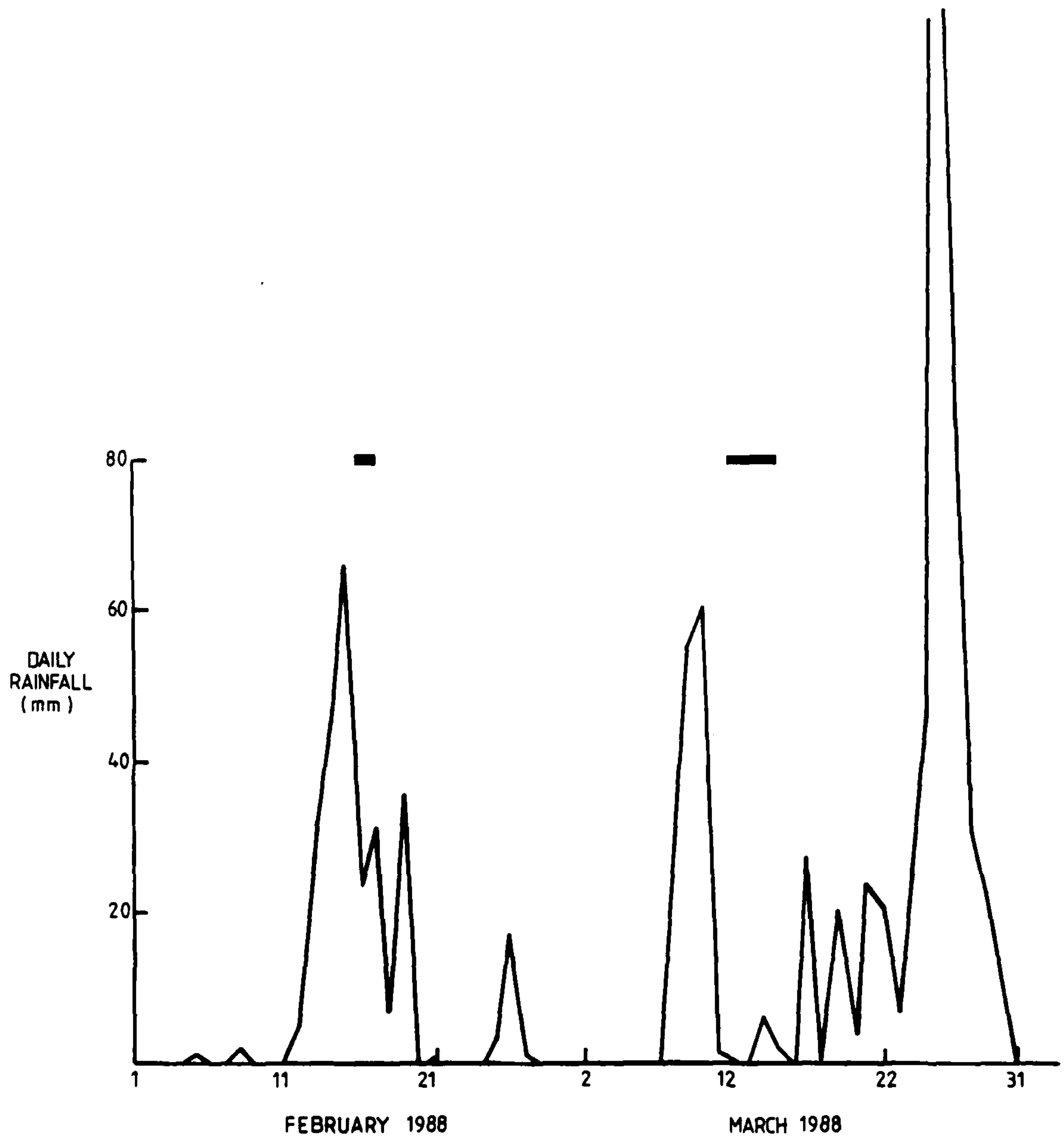


Figure 18. Daily rainfalls, up to 0900 on dates shown for Thursday Island. Solid bars show times of cruises

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17 SUMMARY OR ABSTRACT
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The turbidity in the eastern half of Torres Strait, along with other relevant variables, was investigated on two oceanographic cruises in early 1988. Turbidity was high and variable and a regression equation has been developed relating Secchi disc depth (and thence underwater visibility range) to water depth and wind speed. This equation covered 71% of the rms variation in Secchi disc depth. Turbidity was approximately constant with depth in weakly stratified waters, except when they were particularly turbid (attenuation coefficient >1.0 m^{-1}) and then turbidity generally increased with depth with, in some cases, maxima or minima occurring within the water column. Where the temperature and salinity varied markedly with depth a more turbid lower layer was also present. On the second cruise there was a significant correlation between salinity and turbidity in the central waters of eastern Torres strait which had low salinity, and the possible origin of this low salinity water body is discussed.

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